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Field test of in situ sensor technology for process-based soil gas monitoring

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Abstract

A process-based approach to soil gas monitoring at geologic carbon storage sites may provide an accurate, simple, and cost-effective alternative to other soil gas methods that require lengthy background data collection and complex statistical analysis. However, in order for this method to be implemented on an industrial scale, continuous smart data collection of the necessary parameters for a process-based analysis (e.g. N_2, CH_4, CO_2, O_2 and H_2O) is required. Commercially-available sensors for CH_4, O_2, relative humidity (RH), and CO_2 were screened and found to possess factory-derived accuracies that meet the desired specifications for implementing the process-based method in the field; however appropriate sensor technology for N_2 is not currently available. We report the preliminary results of a field test to develop a method for continuous process-based data collection using commercially-available, automated sensors that measure CO_2, CH_4, O_2, temperature, RH, and pressure, and deriving N_2 by subtraction.

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Keywords: Process-based; soil gas;CCS;continuous monitoring;sensors; cost-effective

1. Introduction

Soil gas geochemistry is an accepted technique for monitoring terrestrial geologic carbon storage sites for near-surface CO_2 that may have leaked from a deep storage formation [1,2,3,4]. As soil gas measurements are point

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measurements, risk assessment commonly informs and directs soil gas monitoring to the most likely areas of CO_2 migration (e.g. near faults, fractures, or wellbores). Such a targeted monitoring approach focuses on obtaining measurements within several compact (e.g. 100 m x 100 m) areas of interest within the larger area of review. If anomalous CO_2 gas concentrations are detected, they are then attributed to either natural variation within the environment or the arrival of a leakage signal into the near-surface [5]. If a leakage signal is identified, reliable and accurate means of quantifying the leakage would be needed to supply an optimized method for accounting of credits, assessing environmental impacts, and predicting cost of remediation if needed.

A process-based approach to soil gas monitoring is increasingly being applied at geologic CO_2 storage demonstration sites as a potential method for near-surface soil gas monitoring, verification, and accounting (MVA) [6, 7, 8, 9, 10]. This approach does not rely on comparing pre- and post-injection CO_2 concentrations, but instead uses relationships between the coexisting gases of CO_2, O_2, N_2, and CH_4 to promptly detect a leakage signal in the vadose zone. Implementing a process-based monitoring approach currently requires periodical sampling of discrete locations for analysis with a gas chromatograph (GC). For environmental monitoring, GC analysis is relatively inefficient, requires use of a consumable carrier gas, and does not directly measure Argon (Ar), which is estimated based on N_2 concentrations, or water vapour, which is assumed under all conditions to be 2.3% (the vapour-saturated condition at 20°C and 100 kPa). Developing the capability for automated data collection and continuous measurement of all gases necessary for a process-based analysis will be a significant improvement over the current application. Assuming that areas of highest leakage potential into the near-surface are correctly identified, continuous monitoring within targeted sites will provide the temporal data density needed for assurance that no leakage occurs. The complete data set afforded by continuous monitoring may be important to alleviate public concerns about the near-surface environment and will increase defensibility in case of litigation. In the event that a CO_2 leak is detected, continuous monitoring of any on-going CO_2 flux will support updates to CO_2 inventory reporting and will also help evaluate the effectiveness of any mitigation measures designed to control leakage.

2. Objectives and approach

In order to understand if currently-available sensor technology could ultimately provide continuous smart data collection for the process-based leak detection method, small commercial sensors were field-tested within the vadose zone at two localized sites within a typical Gulf Coast, USA oilfield. Continuous simultaneous gas concentration measurements were taken using both the GC and commercial sensors over a period of several days within shallow boreholes at each localized site. The response of each measurement device was evaluated both as a function of environmental variability during baseline conditions and while 'spiking' the system with various gas mixtures. The aim was to investigate if an approach using sensors can produce data quality that is similar to or better than the current approach to process-based monitoring. Field validation and performance assessment of the two methods were accomplished by:

1. Devising a method for reducing sensor data to determine parameters not directly measured by sensors (Ar, H_2O, N_2)
2. Comparing the precision of the two measurement types as a function of environmental variability
3. Assessing the accuracy and error of sensor measurements relative to "true values" defined as GC measurements
4. Comparing N_2 values inferred by mass balance of sensor data to N_2 values measured by the GC
5. Addressing the validity of assuming water vapor at 2.3%

3. Methods and materials

A total of nine continuous monitoring tests were conducted within two 1.3 m deep hand-augured boreholes. Non-dispersive infrared sensors were used to measure CO_2 and CH_4 concentrations and galvanic cell technology was used to measure O_2 concentrations. Water vapour was derived from humidity and temperature measurements and N_2 was derived by subtraction. Seven commercially-available sensors comprised the monitoring array for the field tests: Vaisala Carbocap Carbon Dioxide GMT 220 series (0 to 2000 ppm and 0 to 20%), the Dynament MSH-P-HR High Resolution Methane Sensor, Alpha Omega Series 2000 Percent Oxygen Analyzer, the Vaisala Humicap Humidity and Temperature HMT130 sensors, and the Vaisala Barocap Barometer PTB110. Gas concentration tests consisted of two periods of initial background monitoring followed by 'injection' or 'spike' tests. Injection tests involved

introducing 21 kPa of different compositional gas mixtures into a 20 cm monitoring interval at 1.3 m depth to determine the response of sensors and the GC to changing gas concentrations. Each injection test consisted of a period of background monitoring followed by introduction of air and/or gas mixtures into the borehole.

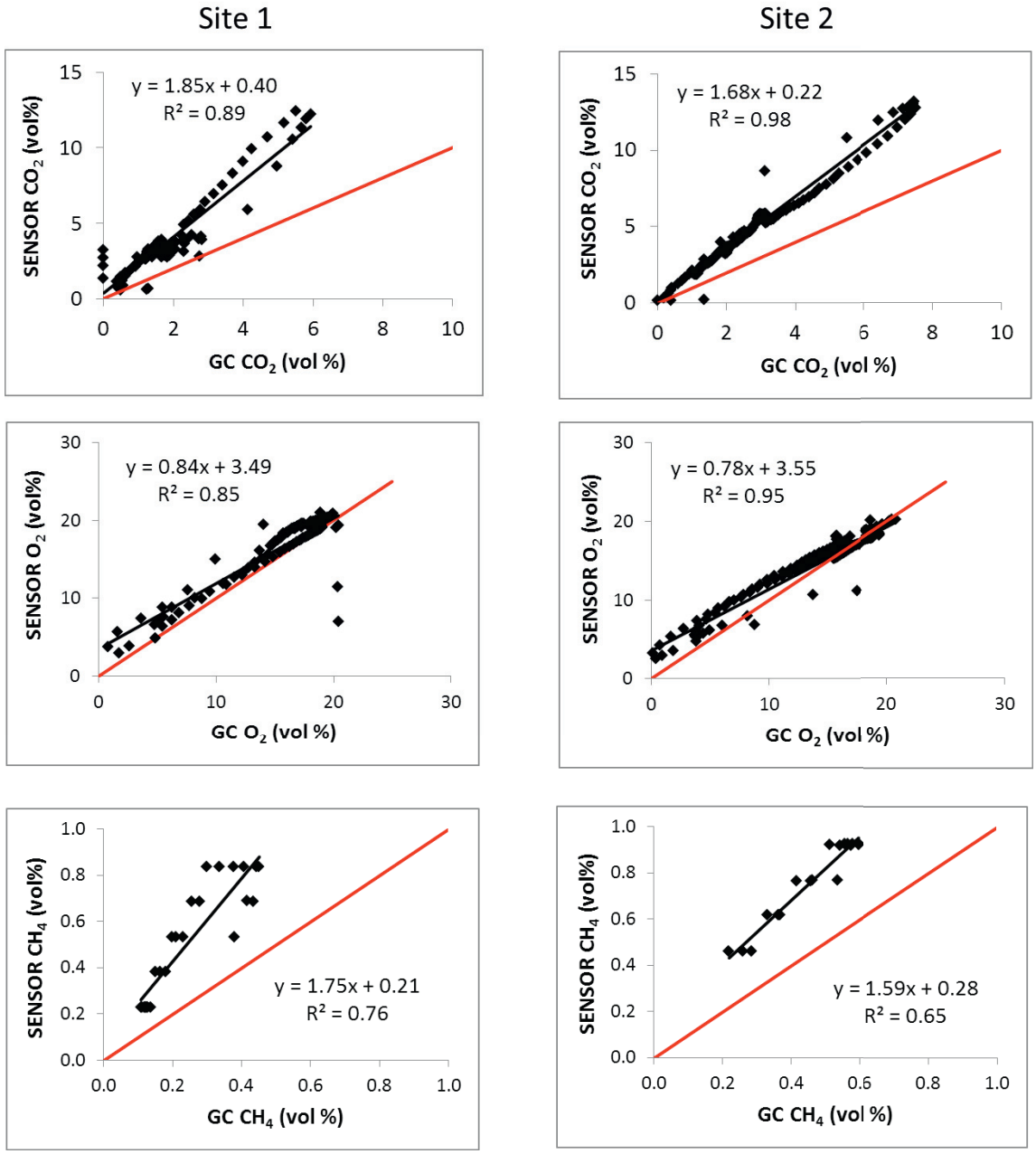

Fig. 1. Regression analysis comparing sensor data and GC data for Site 1 (left set) and Site 2 (right set). Perfect match between the two data sets would yield a regression with a slope of 1(red line). The data show that galvanic cell measurements are more accurate than NDIR. Discrepancies between NDIR and GC data increase at higher concentrations. Discrepancies between galvanic cell and GC data increase at lower concentrations.

4. Results and discussion

Overall response times of the sensors and GC are comparable: however, sensor measurements conducted with NDIR technology consistently measured significantly higher concentrations of CO_2 and CH_4 compared to the GC. This effect became more pronounced at higher gas concentrations (Fig.1). Galvanic cell technology tended to measure lower concentrations than the GC. Subsequent lab testing of the sensors showed factory calibrations remained valid after field tests ruling out sensor malfunction as the source of the discrepancy.

The results indicate bias in the data comprising significant NDIR sensor (CO_2 and CH_4) error, and a lesser degree of error from galvanic cell (O_2) technology. A method for reducing sensor data to acquire functional gas concentrations is possible: however, neither NDIR nor galvanic cell technologies consistently produced data in the field with the necessary quality to perform process-based monitoring at geologic carbon storage sites. Discrepancies between sensor and GC measurements are likely the result of field conditions during deployment; however, there was no apparent effect of environmental variability on parameters such as total pressure, RH, or temperature on sensor functioning. None of the CO_2 measurements, 12% of the CH_4, and 31% of O_2 measurements fell within the acceptable accuracy range of a GC. Application of manufacturer's correction factors to the data result in small changes that do not significantly correct data quality. This phenomenon of site-specific bias has been reported in the literature by other researchers [11,12,13], but the source of the bias remains unknown. The results suggest that further testing of commercial sensors in order to understand the discrepancy of manufacturers reported accuracies and those observed in the field. At the same time, continuation of development of field-deployable sensor technology should continue.

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